# Assessing relative importance of factors affecting Bay-Delta pelagic fish abundance

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Four pelagic fish (two listed under state and/or federal Endangered Species Acts) in the Bay-Delta Estuary have experienced sharp declines, approaching 100%, in abundance in the last decade. These declines have not only focused national attention on this estuary, but have also provoked a growing recognition of the multiplicity of factors that might have caused those declines and a recognition of profound changes in the food web, hydrology, and landscape attributes that might lie at the root of those abundance declines. Maybe all of these changes, some occurring decades ago, must be addressed to comply with the legal mandate to solve the pelagic fish problem and to achieve other environmental goals (about which there is not agreement). However, this will be an expensive fix, and some parts of it, such as converting subsided islands back into tidal marshes laced with interconnecting channels or removing levees and dams that, among other things, protect urban and agricultural lands from floods, are infeasible at any price.

It is, therefore, imperative to focus on the causes(s) of abundance declines in the four pelagic fish, especially the endangered longfin and delta smelts. If we knew what caused those declines, we would know to what extent each of the profound, historical changes was responsible. More importantly, we might find that the cause was of more recent origin, not so profound and, therefore, more easily addressed. In other words, identification of the cause(s) should reveal whether we are dealing with a problem of profound ecosystem proportions requiring as much restoration to pre-European settlement conditions as possible or a problem of more manageable proportions.

Identifying those causes has been a problem. The list of factors (stressors, drivers, etc.) with plausible mechanism of effects is long. Many factors are interrelated. The initial challenge is making the list of candidate factors manageable, by categorizing or subdividing them. Then, we must compare them to distinguish between important and unimportant ones.

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One way of approaching the problem is particularly applicable to this estuary because of the large amount of data available on most candidate factors and the fact that while four species have declined in abundance, others have not, and some have increased in abundance.

This approach first segregates factors into two groups, those factors with direct effects on abundance and those acting through factors with direct effects. This segregation continues by identifying factors with direct effects on factors directly affecting fish, and so forth, until each factor is placed in a hierarchy in accordance with its mechanism of effect. Figure 1 is one example of such an arrangement, an "effects hierarchy," in this case, for delta smelt.

Other methods of categorization have been used (top-down and bottom-up, endogenous-exogenous, etc.), which are not necessarily relevant to fish. Fish do not "care" whether the factor is bottom up or top down. Fish only respond to factors that directly affect their survival and reproduction, and, therefore, their abundance. That's why it is appropriate to focus on factors with direct effect. A primary advantage of this approach is that it reduces the candidate list of factors to a tractable number, approximately ten or so, that directly affect the desired fishes. These include fecundity, food availability, predation, entrainment, contaminants acting directly on fish (as opposed to the food web), temperature, turbidity effects on feeding success, and extent of spawning habitat.

Some factors appear at numerous locations in the effects hierarchy, each location reflecting a different link with fish abundance. This is an important for identifying effective management actions. Consider, as an example, flow, a factor with many mechanisms of effect. Flow affects turbidity, influencing feeding success of some larval fish as well as predation; flow dilutes contaminants or washes them into water; flow affects salinity, influencing the distribution of fish; flow can transport some life stages; flow affects entrainment at the export pumps and other diversions. If flow is an important factor affecting fish abundance, we must know why it is important and how it acts as a
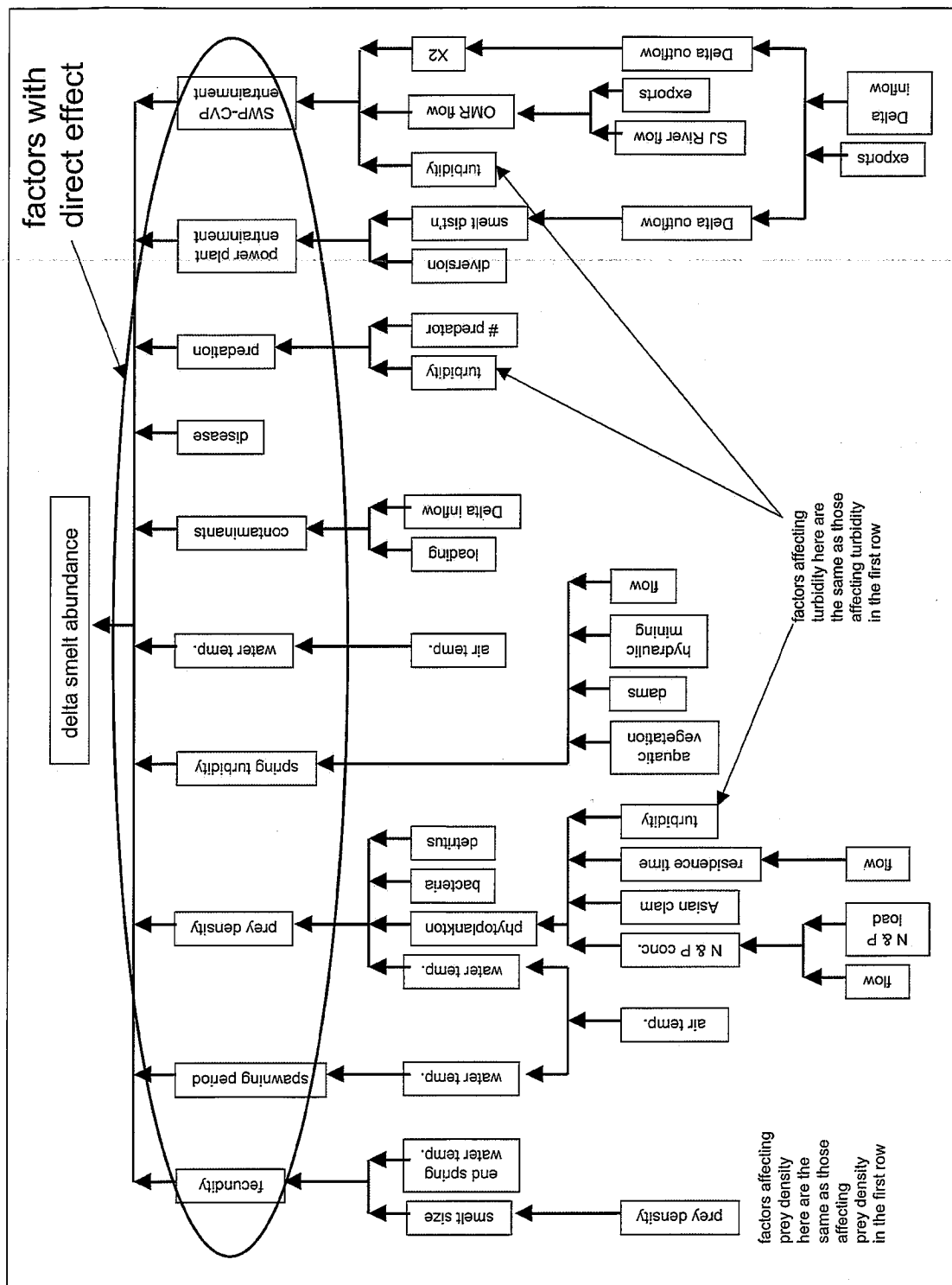
Figure 1. Example effects hierarchy for delta smelt

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stressor. Otherwise, serious management errors can be made. If flow acts through turbidity and turbidity is important, there might be few management options available. If flow dilutes contaminants and contaminants are important, control of the contaminants might be the effective management action. If flow acts through entrainment and entrainment is important, limits on entrainment might be effective. So, in the case of flow, important information can be obtained by first identifying the most important factors directly affecting fish and seeing how flow affects each of those factors. If turbidity and contaminants are not important in determining fish abundances and entrainment is, flow is then important because it affects entrainment, and not because it affects turbidity or contaminants.

Each desired pelagic fish species and the life stage of each fish has different ecological attributes and responses to different stressors, so they may have different hierarchies of effects.

Unlike other conceptual models, this approach suggests a logical analysis, a hypothetical example of which is shown in Figure 2. First, you must identify the most important, directly-acting factors, then, the most important factors directly affecting the important factors with direct effect, and so forth, in a step-wise analysis down the important vertical paths of the hierarchy. This will elucidate important vertical paths of the hierarchy, allowing identification of factors amenable to feasible and effective control.

In each step, a limited number of factors is analyzed, reducing problems arising from collinearity. In contrast, if all factors are treated equally, disregarding their effect mechanisms, factors correlated with directly acting factors and having lower measurement error than directly acting factors can displace directly acting factors in statistical analyses, producing misleading results (see Zidek 1996).

An approach that begins with an effects hierarchy for each species allows two kinds of analysis of the four Bay/Delta pelagic fish. The first uses effects hierarchies for each of the fishes to identify common factors responsible for their declines. Because the
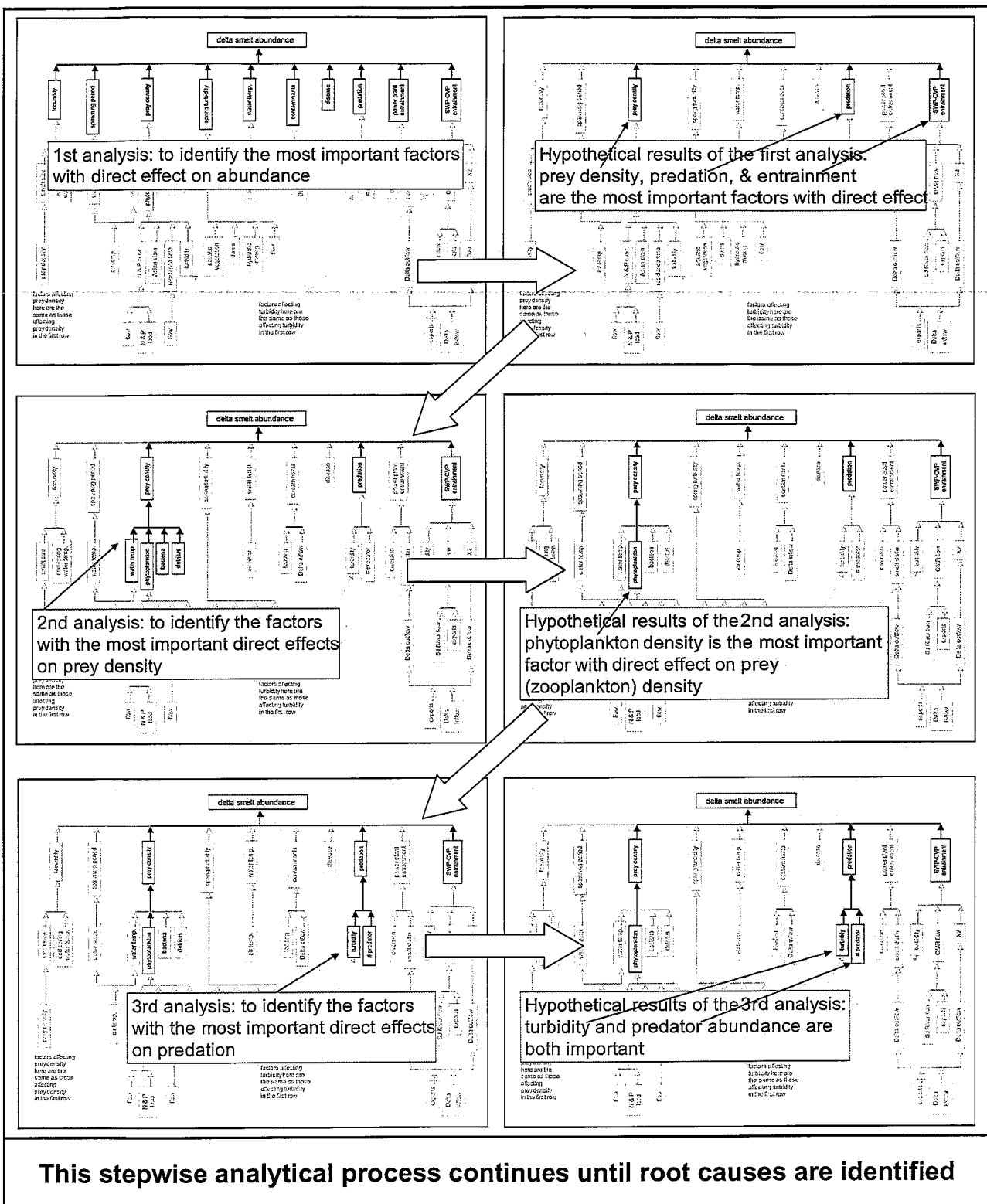
Figure 2. Hypothetical example of using the effects hierarchy to identify important factors and the mechanisms by which they act.

abundance declines all occurred at about the same time, it is reasonable to assume that a same factor or combination of factors was responsible. Of course, the abundance decline for each fish might have had a different cause, and their virtually simultaneous, near-100% declines could have been a coincidence. In fact, that appears to be the case for salmon, which also experienced sharp declines in the same temporal window, but causation is generally attributed to ocean conditions, which would not have been expected to cause the Delta pelagic fish declines. The temporal coincidence of the pelagic fish declines strongly suggests a common cause and demands a serious attempt to identify the common factor or limited number of factors, before concluding that each decline resulted from a different factor.

If common factors are found, we need to know how important each factor is, relative to others. The semi-qualitative analysis above might identify the common cause, but quantitative analysis is necessary to identify management actions.

A second, more definitive, quantitative analysis uses the effects hierarchy for each fish in life cycle models or multivariate statistical analyses. Quantitative analysis might be the only way to identify important factors with reasonable confidence. One primary reason is the possibility that density-dependent factors contribute to determining population size in one or more of the pelagic fishes. There is evidence of density dependence for delta smelt (Bennett 2005). Density dependence makes single- or limited-factor analyses inappropriate. If there is density dependence, quantitative analysis of a single factor (say, prey density) would require that factor to simulate lower-than-expected abundance or survival, caused by density dependence at higher abundances. If the factor analyzed cannot meet that requirement, its importance might not be revealed. Figure 3 shows artificially generated data as an example. Assume that a factor, say water temperature, actually explains most of the difference in end-of-period abundance that is not explained by beginning-of-year abundance. If there is density dependence, the bottom line shows how end-of-period abundance relates to beginning-of-period abundance, and the difference between this line and each data point would be explained by water temperature. However, if density dependence is not accounted for, that amounts to

assuming that the top line, representing density independence, relates end-of-period to beginning-of-period abundance. A statistical test to see if water temperature explains the difference between each data point and the top line is unlikely to show that water temperature is important, even though, in this example, it is the most important factor, along with beginning-of-period abundance.
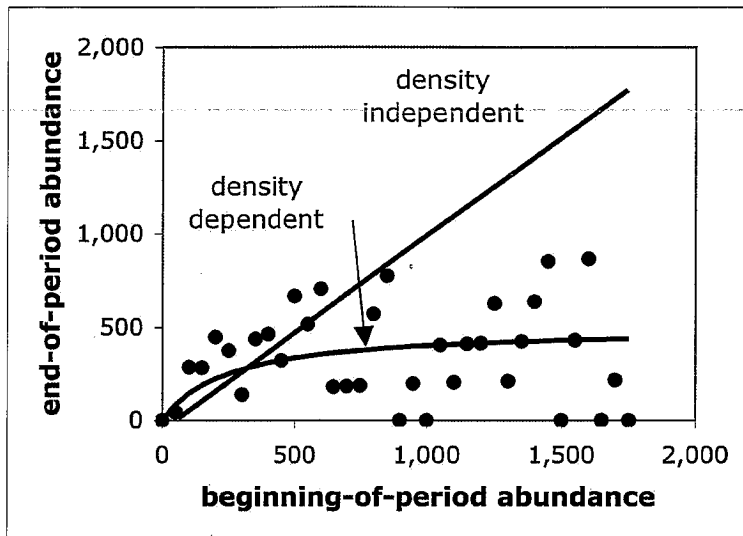


Figure 3. Hypothetical stock-recruitment relationship showing data and line of best fit for density dependent relationship (bottom line) and incorrect line depicting density independent relationship (top line)

Identification of important factors is sensitive to the care taken in quantifying those factors. If affected life stages, co-occurrence of the factor and fish, and prey selectivity, are not considered in factor specification, important effects may be missed. Prey density, expressed as an annual average of the sum of many zooplankton, may show no statistically significant effect, but expressing prey density in terms of preferred zooplankton for particular life stages, and weighting prey densities to reflect the spatial and temporal distribution of life stages can reveal important effects.

Density dependence and the requirement for carefully specified factor values make quantitative analysis essential. In contrast, visual inspection of effects hierarchies indicates qualitative analysis is inappropriate and analyses relying largely on descriptive biology can be misleading.

In summary, the key to understanding the roles of specific environmental factors in the pelagic fishes declines is to identify factors directly affecting fish abundance, arrange all other factors according to their effects on directly acting factors, focus analysis on directly acting factors, carefully specify factor values, and use quantitative analysis (life cycle models or multivariate statistical) that reflect the hierarchical nature of effects.

**References**

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